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Offshore wind energy development in China: Current status and future perspective

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ABSTRACT

Year 2010 is the significant year of offshore wind power development in China. The first national offshore wind power project is connected to the grid, and the first round of concession projects marks the strong support from central government. It is foreseeable that offshore wind power capacity in China will expand rapidly, and play a notable role in the transition to a sustainable energy system, therefore, the understanding pattern of it is crucial for analyzing the overall wind market in China and global offshore wind power development. This paper firstly provides an overview of global offshore wind power development, then in China, including historical installation, potential of resources, demonstration and concession projects, and target of development. Furthermore, a comprehensive overview of advantages and challenges for developing offshore wind in China is presented. Based on this, analysis on current policies related to offshore wind power and their implementation, current wind farm developers and turbine manufacturers as well as technology transfer and development of China's offshore wind industry is done. All the previous analysis generates complete evaluation of current status and future perspectives of China offshore wind power development, based on which some policy recommendations for sustainable development of offshore wind power are made.

Contents

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1. Introduction

After dramatic growth of onshore wind power from first round of concession in 2003, China has also initiated the first round of national-level offshore wind farm concession projects in 2010. Taking incredible increase from 567 MW in 2003 to nearly 13,803 MW in 2009 after concession as a benchmark [1], it is foreseeable that offshore wind power development in China will boom dramatically in the future. This kickoff of offshore wind power is based on the strong support on wind power development from China government in order to cope with the increasing concern of energy security and climate change.

China has become the world second largest energy consumer, and IEA predicted that its primary energy demand will double from 2005 to 2030 [2], while the energy resources per capita in China is much smaller than the world average level [3]. Therefore, import dependence of energy keeps increasing. With regard to crude oil, proportion of import has grown from 42.9% in 2005 to 48.3% in 2008 [4], which has severely influenced the sustainable growth of China's economy.

Also, China has made strong commitment of emission reduction, which forces carbon intensity in 2020 a 40–45% decline with baseline of 2005 [5]. President Hu Jintao has clearly stated that stimulating non-fossil energy to 15% of primary energy consumption in 2020 is a key pathway of achieving the reduction objectives [6].

Since wind power is one of the most mature and economical renewable energy technologies, it will definitely play a notable role in the transition to a sustainable energy system in China. It is estimated that wind energy would take about 2% of the China's total primary energy consumption in 2020 and about 6% in 2030 under the scenario which balances economic, social and environmental sustainability with multilateral support mechanisms [7]. For China's total power generation installations, it is estimated to take about 2.5% of in 2020, and 15% in 2030 [8].

China has successfully encouraged onshore wind power development in recent years. Considering premium space is becoming scarce for the installation of onshore wind turbines, offshore wind energy is getting more and more attractive due to the several advantages – vast deploying area, higher speed and more stable wind, closing to load center, and so on. Besides, Chinese wind power manufacturers have developed their capabilities rapidly in recent years with onshore wind development, and have significantly narrowed the gap between these capabilities and those of leading international suppliers, which also makes China ready for offshore wind power leap.

This paper carries out a comprehensive study on offshore wind power in China, which has seldom been done before. It is structured as follows: in Section 2, we first provide a brief overview of the development of the global offshore wind power. Section 3 continues with an overview of current offshore wind power status in China from perspectives of potential for offshore wind energy, existing projects, as well as advantages and challenges for offshore wind development. Section 4 details planning and policies for China's offshore wind power. Section 5 focuses on the situation of the manufacturers, the technology transfer and technology development of China wind power industry. In Section 6, we discuss several issues and trends of offshore wind development in China, such as size and quality of offshore turbine, grid connection of offshore wind power, coordination between central and local government, cost and economical analysis, low bidding price in concession and SOEs' participation, and international support. Section 7 concludes the paper.

2. Global status of offshore wind energy

The first offshore wind turbine of the world was installed in 1990 in Sweden Nogersund. In the following 20 years, Denmark, Sweden, the Netherlands and the UK have built a number of demonstration offshore wind power projects which were mainly funded by the Government and research institutions. The complete of Horns Rev 160 MW offshore wind power project in 2002 in Denmark marks the offshore wind power has stepped to a new stage. The project greatly enlarged the size of the project, before when, the largest offshore wind power project scale was only 40 MW. After that, Denmark, the UK, and other European countries have developed a number of projects. At the end of 2006, Europe had the operating wind farms in Denmark (398 MW), UK (304 MW), Ireland (25 MW), Sweden (23.3 MW) and the Netherlands (136 MW). It accounted 1.8% of the installed wind energy, but 3.3% of the wind energy production [9]. In last few years, there was about 150 MW increase of global offshore wind power installations annually, and the average growth rate is 58% from 2000 to 2007 [10]. By Jan 2009, the world had got 1470 MW wind power installed, all of which is in Europe. Fig. 1 shows the growth trend of world offshore wind installation in the new century.

In February 2007, European member states made a commitment to increase the total share of renewables in primary energy consumption to 20% by 2020 [11]. It has been estimated that the cumulative installed offshore wind power will reach 4000 MW by the end of 2011 [12]. However, offshore wind energy development is taken stably and steadily in Europe, mainly because the cost of

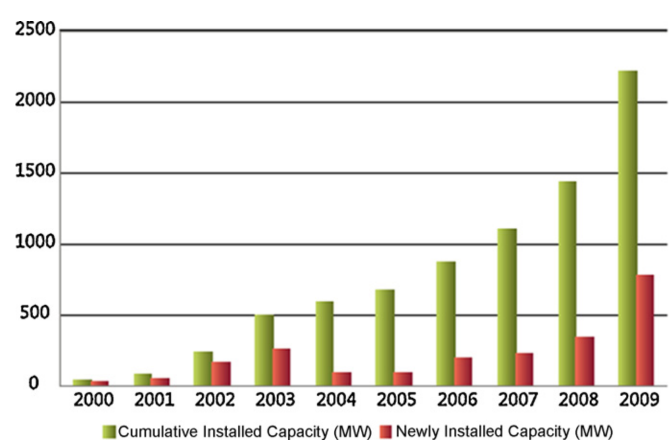

Fig. 1. Global offshore wind installation growth (2000–2009). Source: [1].

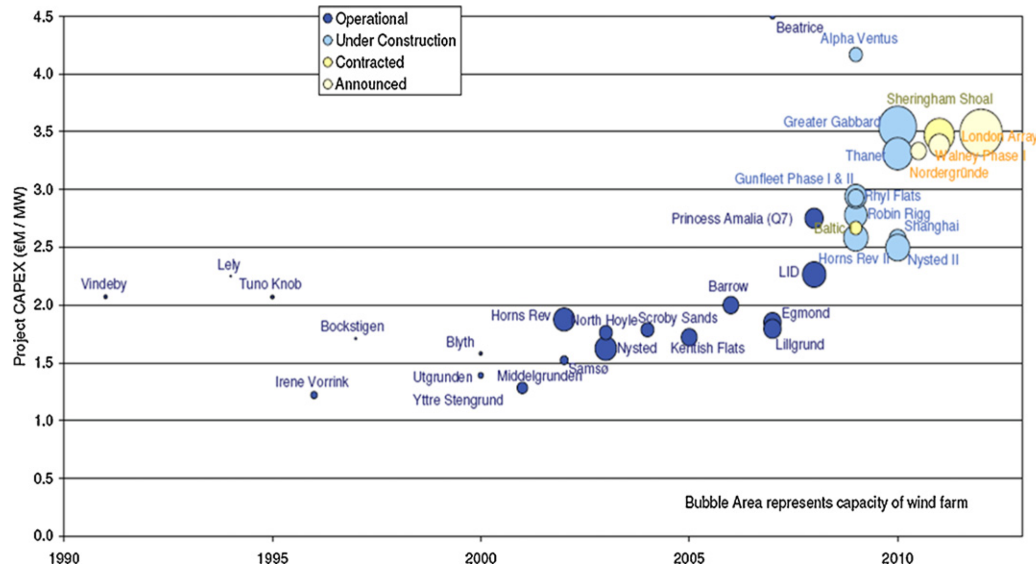

Fig. 2. Historical CAPEX of offshore wind projects in Europe (1990–2015).

Source: [13].

offshore wind does not show an obvious decline, which is shown in Fig. 2.

Beside Europe, North America is still at the planning stage by the year 2008, despite the great potential of 907 GW within a 50 nautical miles limit.

3. Overview of China offshore wind energy

3.1. Potential for offshore wind energy

China has relative abundant wind energy resources because of its location at the monsoon zone. With the advantage of long and winding coastal line, regions in the south-east coast and nearby islands including Shanghai and the provinces of Shandong, Jiangsu, Zhejiang, Fujian, Guangdong, Guangxi and Hainan have great potential to develop offshore wind power. The annual wind power density reaches above 200 W/m^2 within the areas 10 km from the coast, and over 500 W/m^2 on the adjacent islands, such as Tai Mountain, Pingtan, Dongshan, Nanlu, Dachen, Shengsi, Nanao, Mazu, Magong and Dongsha [14].

There are several analysis assessing the potential of China offshore wind energy. A long-standing ‘preliminary’ assessment carried out by China Meteorological Administration at the beginning of 21st century indicates that offshore (water depths less than 20 m) wind power had 750 GW which is as large as 3 times of the onshore (250 GW) [15]. However, at the end of 2009, China Meteorological Administration released a new wind assessment, based on measurements at 50 m height. This showed that China has a potential to develop 2380 GW of class 3 wind power (avg. wind power density >300 W/m^2) and 1130 GW for class 4 (average wind power density >400 W/m^2), while the offshore potential (water depth 5–25 m) reaches 200 GW for class 3 [16]. Another research carried out by the UNEP in cooperation with the US National Renewable Energy Laboratory (NREL), calculated the exploitable onshore wind resource of 1400 GW (at 50 m height) and 600 GW of the offshore [17]. The newest estimation by WWF, China Wind Energy Association and Sun Yet-sen University shows the total technical potential of China along the entire coast from Liaoning to Hainan is 11,580 TWh/year. Fig. 3 shows their result of China’s offshore annual wind energy density, 100 m within 100 km [18].

Although with uncertain expectations for China’s offshore wind market, and the less cost to develop onshore wind farm, there is still a major opportunity for the country to power up its coastal regions from turbines at sea. As AMSC’s Poor says, there is a “tremendous opportunity” – “What we see from our perspective is that they are pursuing the offshore market very strongly. Whether (the potential) is 750 GW, 600 GW or 200 GW, it’s going to be a very significant part of the overall wind market in China going forward [16].”

3.2. Existing offshore wind power projects

The first pilot offshore wind power project in China is one 1.5 MW wind turbine installed upon jacket at the Suizhong 36-1 oil field in Bohai Bay, being linked to the national grid in November 2007 [19]. However, the first commercial offshore wind project – the 102 MW Shanghai Donghai Bridge wind farm, which is consisted of 34 Sinovel (3 MW) turbines off Shanghai’s coast, has not been operated until 2010. This project is specially designed for World Expo 2010 in Shanghai with strong political objective, and all the 34 turbines are connected to the grid in June [20]. Three months later, the world first inter-tidal wind farm – Rudong offshore wind project is accomplished by Longyuan Group. This project is an important trial for inter-tidal wind turbine installation. Longyuan Group has successfully installed 16 turbines from 9 domestic manufacturers with total capacity of 32 MW. There are six 1.5 MW turbines, two 2.5 MW turbines, and two 3.0 MW turbines, all of which have been connected to grid by the end of September [21].

More importantly, in May 2010, the first round of concession projects was started. There are four projects with total capacity of 1 GW in this round, and all of them are located in Jiangsu Province – two offshore projects in Binhai and Sheyang with 300 MW capacity respectively and two inter tidal projects in Dafeng and Dongtai with 200 MW capacity respectively. In October, the concession result was revealed. All the developers and manufacturers are domestic players. Another notable phenomenon is that all the bidding prices for these projects offered by the successful bidder – about 0.7 RMB – are much lower than expected – 0.9 RMB at least, which is estimated by China Hydro Consultant Group [22].

3.3. Advantages and challenges of offshore wind power

3.3.1. General concerns

Comparing with onshore wind power, offshore wind power has several advantages and challenges in general.

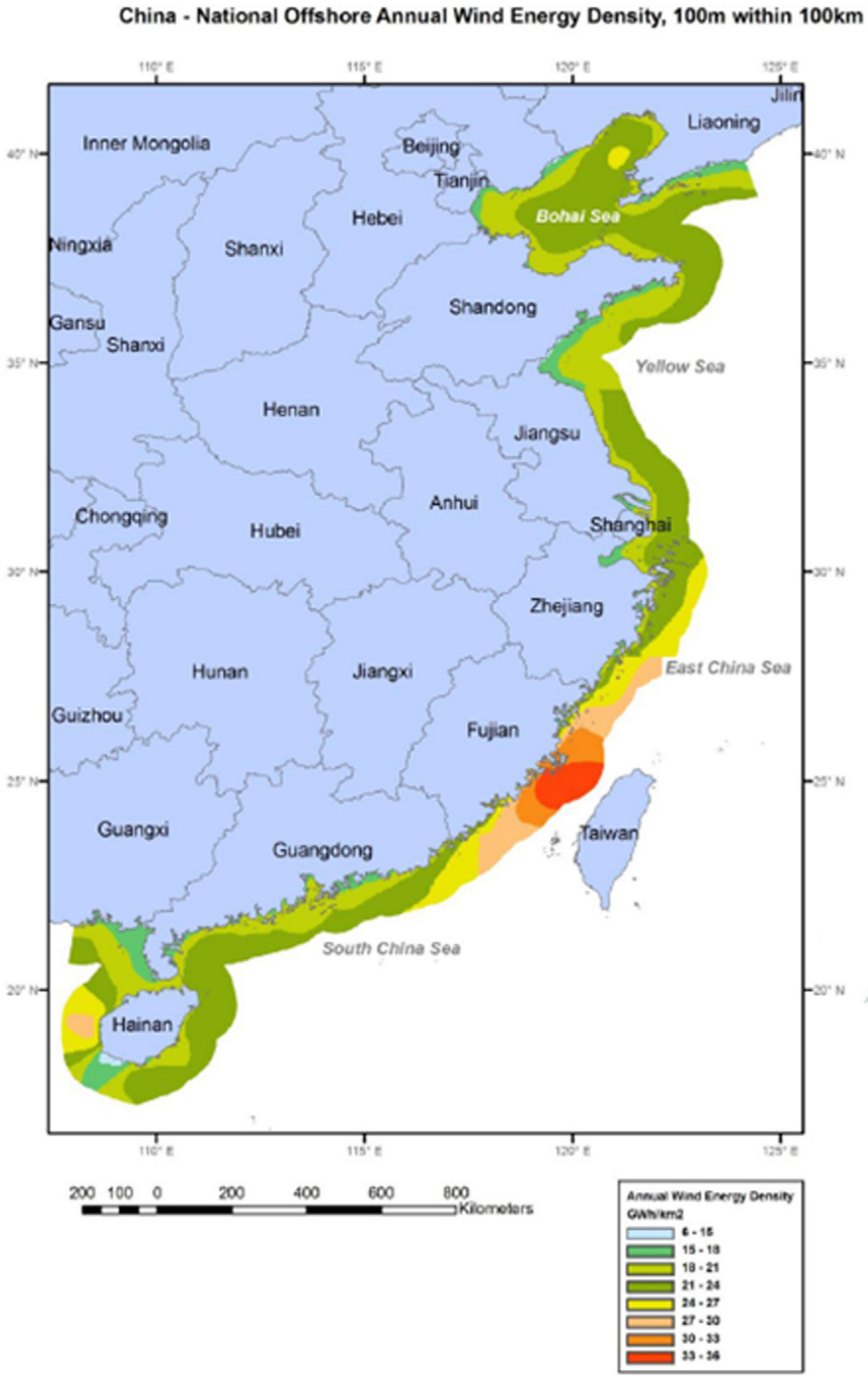

Fig. 3. China's offshore annual wind energy density, 100 m within 100 km [18].

The advantages are: stronger and more stable wind implying greater productivity, issues of visual impact and noise eliminated implying possible use of different designs for the turbines of high efficiency and installation of large wind parks, with no limit on the size of the turbines because there is no limits imposed by road restrictions [23].

The challenges are: 1.5–2 times higher CAPEX than onshore because of towers, foundations and underwater cabling [24]; longer planning phase including environmental, engineering, feasibility and site-specific studies required; 5–10 times more expensive to perform repair offshore due to the need for expensive crane vessels [25]; longer waiting periods for suitable weather conditions for repair and maintenance [26]; less availability of the turbines for locations submitted to harsher environmental conditions [27]; additional cost to use of higher reliability components for the turbines as distance from the shore increases [28]; risk for a shortage of vessels for construction and repair purposes [26]; more severe environmental conditions with wave and current loading, as well as possibly ice loading, and corrosion from salty waters and offshore air. All the above generate big difficulty in the financing of the developers with higher cost and risk [29].

3.3.2. China features

China stands out because of some unique advantages and challenges to develop offshore wind power.

Several advantages are: shorter distance to electricity load center in the eastern and southeastern coastal areas bringing down cost of transmission; no deep coastal waters as those in European countries; low labor cost and abundant experience of construction due to infrastructure and large projects intensively launched in recent years.

Several challenges are: lack of experience, including experience to develop and install 5 MW or larger wind turbine, experience to carry out offshore construction, experience to operate and maintain offshore turbine, and experience to connect large capacity turbine to the grid.

Harsher climate condition – lower average wind speed, frequent typhoon and floating ice. Unlike European countries, China's coastal mean wind speeds are generally lower than the strong 9 m/s typically found across Europe [16], and frequent typhoon makes offshore power in China more challenging. In 2006, typhoon "Sangmei" hit Cangnan Wind Farm directly, causing 20 of 28 turbines to fall [30]. In the north China, floating ice in the winter is also a big threat to wind turbine.

Silt base of inter-tidal zone – to overcome difficulties of tidal and muddy base, China has utilized unique construction patterns and equipments to install turbines in the Rudong inter-tidal demonstration project, for example, using jack-up crane barge, and various of sensors, etc. [31].

More competition with other marine users – besides traditional function of marine zone, such as shipping and fishing, offshore wind power development in China should also consider the military users. Due to unstable political environment of Northeast Asia, a large amount of sea areas are occupied by navy, especially the one near Fujian which is crucial because of the possible conflicts with Taiwan Authorities. This makes the available area for offshore wind power development shrink.

4. Planning and policies for offshore wind development in China

4.1. Planning

Mainland China has 11 provinces and municipal cities with coastal lines, which is shown in Fig. 4.

In April 2009, the National Energy Administration (NEA) required each coastal province to formulate a provincial offshore wind development plan which clarifies potential offshore wind farm with the scale about 1000 MW, and divided China's potential offshore wind sites into three categories, according to the depth of water: an 'inter-tidal' zone for water depth of less than 5 m; an 'offshore' zone for water depth of 5–50 m; and a 'deep sea' zone deeper than 50 m. The provincial governments were required to draft offshore development plans for 'inter-tidal' and 'offshore' wind development up to 2020 [32]. Before 2009, some provinces already formulated planning for offshore wind farms, shown in Table 1.

Table 1
Planning of offshore wind power of coastal provinces in China (2008).

Wind farm		Under construction or completion (MW)	Existing plan (MW)
Hebei	Cangzhou	50	1000
Shandong	Weihai		1100
	Qingdao		1500
	Xiangshui		1000
	Lianyungang		2000
	Rudong		2500
Shanghai	Donghai Bridge	100	
	Fengxian		400
	Nanhui		400
	Hengsha		200
Zhejiang	Cixi		1500
	Daishan		500
	Linhai		200
Fujian	Liu'ao		200
	Nan'ao		300
Guangdong	Jianhua Bay of Lufeng		1250
	Dongshan Sea		<680
Hainan	Floating wind farm	20	100
Total		170	17,600

Source: [33].

Under plans in 2009, Shanghai, Jiangsu, Zheijiang, Shangdong and Fujian hoped to have a combined offshore cumulative installed capacity of 10.1 GW by 2015 and 30 GW by 2020 [34]. Figs. 5 and 6 show the offshore wind power planning in Jiangsu and Fujian.

However, planning in China has always been surpassed, and the growth of wind power is often beyond expectation, forcing Chinese authorities to conduct a series of revisions of their medium-term targets for total installed wind power capacity. In the early of 2010, there even exists study doubting whether the 100 GW for 2020 target can be achieved [35], however, after then, among various perditions in China, even the most conservative one for 2020 has total installed wind power capacity prediction more than 150 GW [36–38]. Analogous to this, there is also great possibility that the offshore power planning surpasses the planned capacity in the future.

4.2. Policies

4.2.1. General wind power policies

The Renewable Energy Law in 2005 is the first national renewable energy law. It gave huge momentum to the development of renewable energy and the wind power has grown at a frantic pace since then. In 2007, the first implementation rules for the Renewable Energy Law emerged, offering further impetus to wind energy development [32].

An amendment to China's Renewable Energy Law was introduced in 2009. Reiterating priority grid access for wind farms, it was a stipulation which had previously not been enforced. The amendment raised the Renewable Energy Premium in November 2009 to 0.004 RMB/kWh, and established Renewable Energy Fund to cover the extra cost for integrating renewable energy. Also, feed-in-tariff regulation took places of two parallel system, with a concession process on the one hand, and the project-by-project "government approval" process on the other. There are four different categories of tariff depending on a region's wind resources, ranging from 0.51 RMB/kWh to 0.61 RMB/kWh, which gave investors a much more clear idea of the long-term framework for the sector [32].

Relevant Provisions for the Administration of the Generation of Electricity Using Renewable Energy Resources issued by National Development and Reform Commission (NDRC) in 2006 has clarified approval right of central and provincial government. Wind projects larger than 50 MW are authorized under a concession process managed by the NDRC, while smaller projects are managed by Provincial Development and Reform Commission. Concessions are allocated typically for a 25-year period in regions preselected. Provincial grid companies are required to sign a power purchase agreement (PPA) with successful bidders. The price at which electricity is delivered to the grid is fixed during an initial period, typically about 10 years, at a level set during the initial bidding process. The price in subsequent years is expected to adjust to the prevailing electricity market price in the region served by the grid [36].

Fig. 4. Coastal provinces and municipal cities of Mainland China.

Investments in renewable energy benefit from favorable treatment both in terms of obligations for value added tax (VAT) and enterprise income tax (EIT). Before 2009, to promote wind energy projects in China, VAT for wind power has been reduced from 17% to 8.5% and the income tax has been reduced from 33% to 15% [39]. In January 2009, a change has been made to the VAT rules that input tax of equipment purchased by developers can be deducted. However, this change has some externalities on wind turbine manufacturing industry, which will be discussed later in Section 6.

4.2.2. Specific policies for offshore wind power

Issued in February 2010, by National Energy Bureau and National Marine Bureau, Interim Measure of Development and Construction of Offshore Wind Power is considered as guidelines for offshore wind power development. This measure has made clear regulations for overall planning of offshore wind power and construction of specific wind power project. Every coastal province should formulate planning for the development of offshore wind power under the guidance of National Energy Bureau and National Marine Bureau. For one specific wind power project, provincial government is responsible for drafting the application materials. When approved by National Energy Bureau and National Marine Bureau, concession process starts to select company. Company which has rights to invest and develop the project should be local or joint-owned that China holds the controlling share. Moreover, the construction and operation of the project should be also under the guidance of these two authorities.

To improve the efficient competition of wind power equipment manufacturing industry, Ministry of Industry and Information Technology (MITT) drafted Access Standard of Wind Power Equipment Manufacturing Industry for the integration of this industry. This draft was issued in March, 2010, and key regulations for manufacturers are listed as follows:

For the initial investment, this standard requires that equity proportion of initial investment of wind power project should be no less than 30%. This is considered as a solution for the "overcapacity" situation of wind power investment;

For the location, this standard requires manufacturers locate their factories near the "wind base" and upstream suppliers to reduce the logistics cost;

For production capacity, this standard requires that manufacturer must have the production capacity of 2.5 MW or more independently, and annual production more than 1 million kilowatts;

For R&D, the standard requires that manufacturer should give priority to development of independent intellectual property rights of wind turbine with unit capacity of 2.5 MW or more and development of offshore wind power equipments.

If issued formally, this standard will greatly influence the offshore wind power industry.

5. Manufacturers and technical transfer and development of wind power industry in China

5.1. Manufacturers

Offshore wind power equipments have more strict requirements. Therefore, there is few player which masters mature products in this area now. In the world market, Vestas and Siemens are leading companies, and they take the major share of the offshore wind power equipment market shown in Fig. 7.

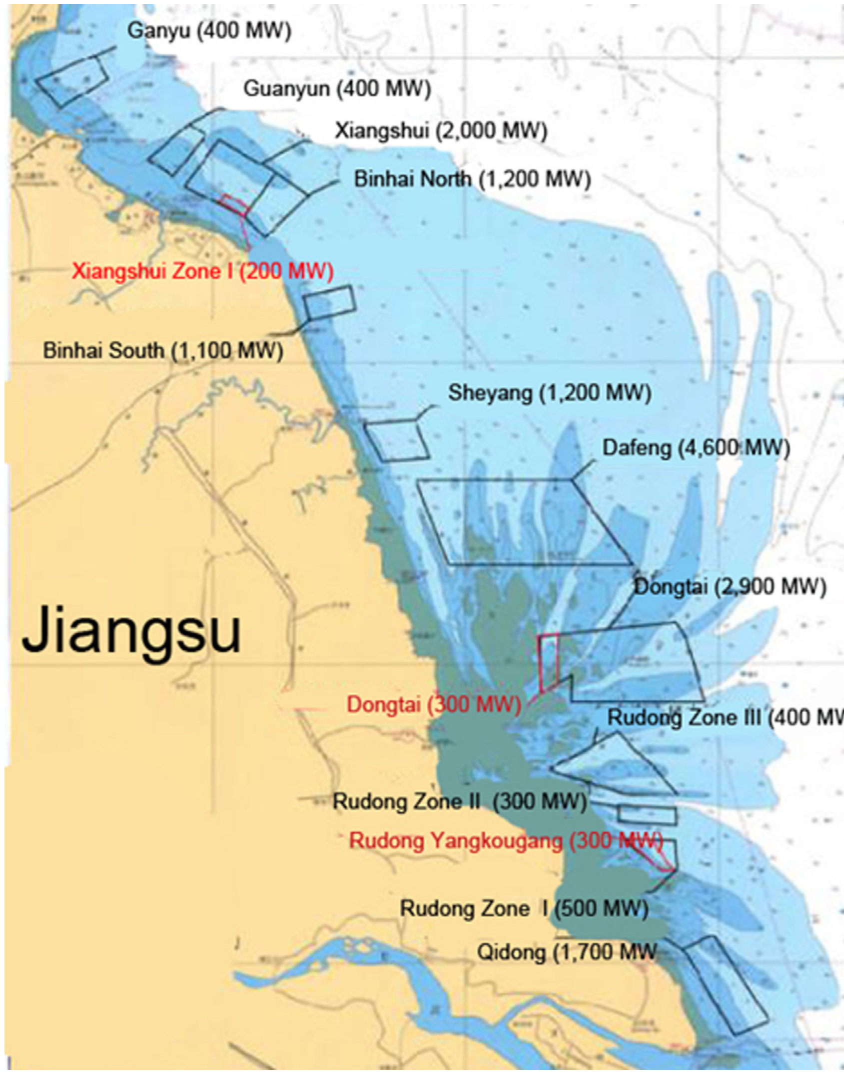

Fig. 5. Offshore wind power planning of Jiangsu Province.

Since offshore wind power market in China has just been initiated, here we just take a brief review of Chinese manufacturers and qualified players in the future according to the standard drafted by MITT.

Chinese manufacturers have developed quite fast in recent years. In 2007, the market share held by Chinese manufacturers was 56% of the total new installations in 2007 [39]. By the end of 2009, there were almost 80 wind turbine manufacturers, 30 of which had actually already sold wind turbines. Already now, the three largest domestic manufacturers (Sinovel, Goldwind and Dongfang) have a combined production capacity of 8.2 GW for an annual market of 13.8 GW. Table 2 shows main types and production capacity of top 10 manufacturers in China by the end of 2009.

Since the drafted standard by MITT requires manufacturers for offshore wind power have production capacity of 2.5 MW or more independently, and annual production more than 1 million kilowatts. Only less than 10 manufactures in China are qualified according to the access standard. This standard will diminish the opportunity to enter the offshore wind market for small manufacturers, and qualified manufacturers will be selected from the top 10 manufacturers mentioned above. By the end of 2009, manufacturers that can produce wind turbine with capacity larger than 2 MW are Goldwind, Sinovel, Dongfang, Shanghai, Zhongchuan, Mingyang, and Vestas in China. Some other manufacturers, such as Siemens, Shanghai Electric and Shenhua Group, XEMC, CSIC, United Power, and Yinhe Avantis Corporation, are busy developing prototypes of large-scale wind turbine. It is foreseeable that the competence of offshore wind power equipment market is intensive although players are much fewer than onshore.

5.2. Technology transfer and development

China is a relatively latecomer in regard to the setting up of wind power industry. Before 2005, there was barely influential wind power equipment manufacturers in China. Nowadays, though China has not mastered all key technologies for offshore wind turbine, turbine used for offshore wind in China is nearly most advanced one, because manufacturers in China have integrated almost all the best technology around world through technical transfer, such as licensing, joint venture, R&D collaboration, as well as independent development.

The first important mechanism of technical transfer is technology licensing. Licensing consists in the permission by the owner of a patented invention to another person or legal entity to perform, in a certain country and for the duration of the patent rights, one or more of the acts which are covered by the rights to the patented invention in that country. Licensing is important for China wind turbine industry, and about 80% percent of manufacturers

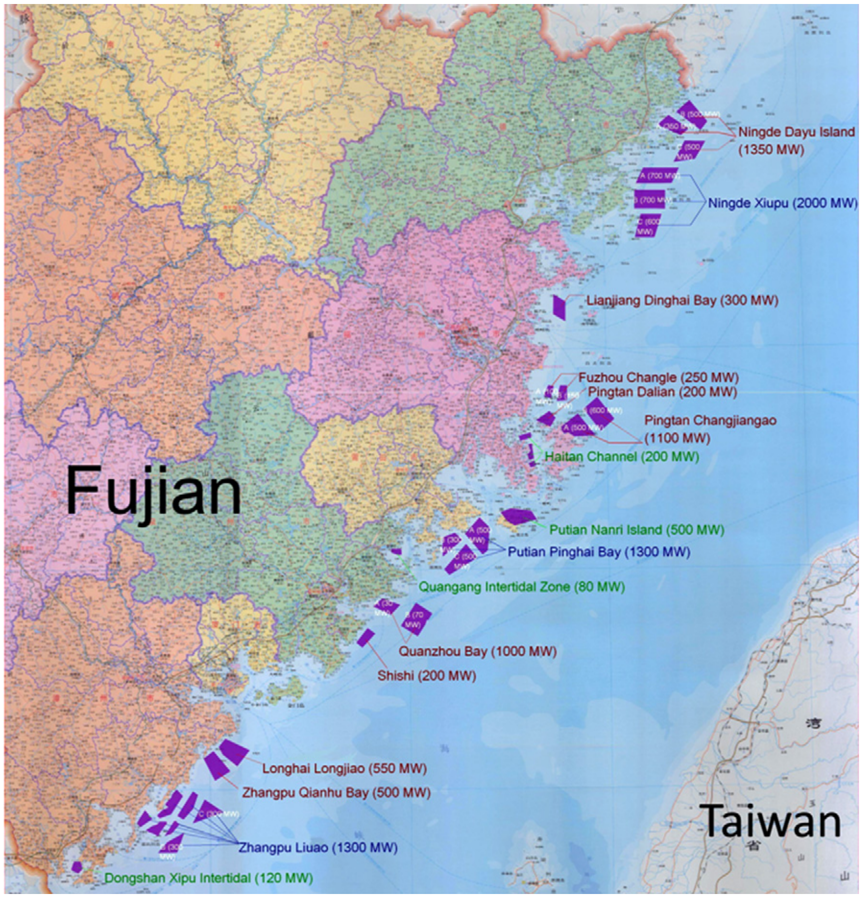

Fig. 6. Offshore wind power planning of Fujian Province.

utilize this approach. Like most large-scale production industry, e.g. automobile and high-speed railway, through licensing, Chinese manufacturers started to learn technology by sharing China's huge market with foreign companies. Licensing has greatly fostered the manufacturing capability of China wind power industry.

Another type of technical transfer is the one that implies the creation of joint ventures (JVs), which is based on the creation of an entity that embraces two or more firms that pool a portion of their resources, in order to create a separate jointly owned organization. Among these joint ventures, the part of Chinese capital mostly comes from the private sector, not state-owned enterprise (SOE). Joint venture is not very successful in China for wind turbine industry, especially for technology transfer. REpower North (China) Co., Ltd. co-founded by REpower, Germany, Honiton Energy, UK, and North Heavy Industry Group, China is one among quite a few successful joint venture companies. However, the success is based on no technology transfer requirement to North Heavy Industry Group.

Collaborative R&D is the most popular for major manufacturers because IPR and know-how are shared during the R&D procedure. With strong imitation and reverse engineering, some Chinese manufacturers obtained capability of wind turbine design. They

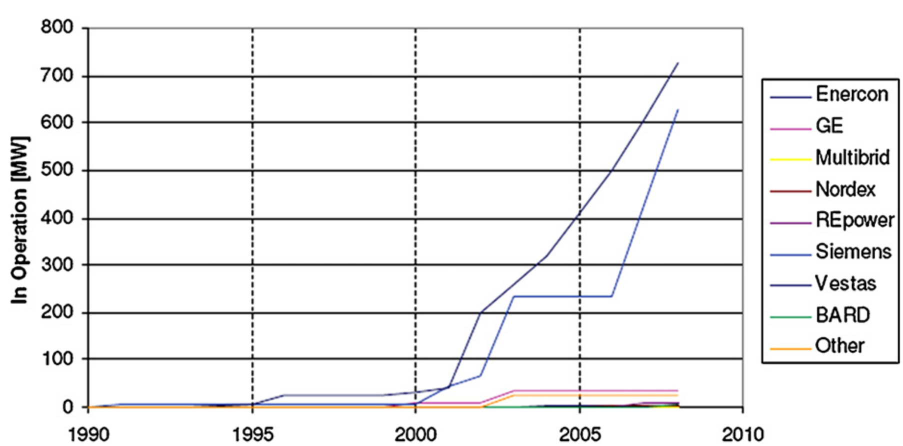

Fig. 7. World offshore wind power market shares (1990–2010).

Source: [13].

Table 2
Main types and production capacity of Top 10 manufacturers in China.

Manufacturer	Turbine type (MW)	Annual production (MW)	Technology source
Sinovel	1.5/3/5	3000	1.5 MW: introduced from Fuhrlander 3.0/5.0 MW: introduced from Windtec
Goldwind	0.6/0.75/1.5/2.5	2200	0.6 MW: introduced from REPower 0.75 MW: introduced from Jacobs 1.5/2.5 MW: introduced from Vensys
XEMC	1.5/2/5	2100	1.5/2 MW: introduced from TMPA 5 MW: introduced from Darwind
Dongfang	1.5/2.5/3	2000	3 MW: introduced from Moventas
Guodian	1.5/3	1000	1.5 MW: co-designed with Aerodyn
Zhongchuan	0.85/2	1000	0.85 MW: introduced from Frisia 2 MW: co-designed with Aerodyn
Mingyang	1.5/3	1000	1.5 MW: co-designed with Aerodyn
Suzlon	1.25/1.5	900	Independent R&D
Vestas	0.85/2.0	800	Independent R&D
Huayi	0.75/1.5	800	0.78 MW: independent R&D 1.5 MW: co-designed with Aerodyn

Source: [40].

always chose to collaborate with licensing issuers or other manufacturers to carry out collaborative research. This mechanism is more efficient in technology transfer because of intensive exchange during the process of R&D, and it becomes the trend of technology transfer. More and more major manufacturers have adapted this approach to upgrade their technical capacity. For example, Sinovel and Windtec co-designed 3 MW offshore wind turbine for Shanghai Donghai Bridge offshore projects, Mingyang and Aerodyn co-designed Super Compact Drive 3 MW turbine. According to the interview with Shi Lei from Goldwind, there is almost no IP conflict in China for wind turbine industry, and most collaboration on technology goes smoothly. Acquisition of foreign company with R&D sector integrated is now also an important approach in collaborative research and development. Like Suzlon finished acquisition of Repower, Goldwind integrated Vensys, XEMC also integrated Darwind to deliver collaborative R&D.

Besides technology transfer, more and more Chinese manufacturers gradually switch to independent R&D to develop turbines that are more appropriate for offshore wind power. Many Chinese manufacturers including Glodwind get financial support from the central government from 863 and other foundation offered by Ministry of Science and Technology. For example, Goldwind is developing direct drive turbines, which needs less maintenance, therefore, for offshore wind turbine which has less accessibility, this kind of turbine may be more appropriate. Mingyang has achieved impressive innovation cooperated with Aerodyn, which indicates the successful development of Super Compact Drive 3 MW turbine. This innovation is quite notable because it totally changes the design of traditional turbines [41].

However, some key parts, such as blade, gearbox, converter, spindle bearings are still not totally localized in China, and the most important reason is not the capability of design, but the capability of material processing. Processing technology in China cannot satisfy requirements for some important parts of wind turbine.

6. Issues and trends of offshore wind development in china

6.1. Bigger turbine?

Due to the higher cost of installation and smaller importance of visual impact, most manufacturers in China are interested in developing bigger turbine for offshore wind. Goldwind is developing 6 MW direct-drive offshore turbine. Sinovel and Dongfang, are also working on designs for 5 MW offshore units, and it is certain they also have plans for larger machines further down the line.

However, bigger is not necessarily better. From turbine perspective, as was recently discussed by Moe, increasing mass of turbine, higher cost of gearbox, and other reasons such as learning effect have made bigger turbine not as efficient as designed [42]. From grid connection perspective, due to lack of offshore power management, larger size of turbine may increase the difficulty for grid connection [15].

6.2. Turbine quality

Comparing with onshore wind turbine, offshore wind turbine should have better quality and reliability to avoid repair and maintenance. That is why European countries are very careful to develop offshore wind, and the cost of offshore turbine has not been reduced in recent years [13]. In China, the installation capacity is skyrocketing, and it is rather fast to develop offshore wind energy just not long after large-scale installation of onshore wind. Therefore, higher risk may exist. In 2010, several accidents caused by wind turbine have already warned the fast growing industry [43–47]. Since most of turbines installed in China has not experienced long time operation, it is estimated that more accidents may happen in the future, for which some experts suggest slower pace for offshore wind power development with higher quality assured.

6.3. Grid connection

Grid connection of onshore wind power has become a hot issue because more than half of the installed wind power has not been connected to the grid by the end of 2009 [48]. This problem is well known caused by the lagged grid construction and lack of capacities of grid management [49]. Although efforts like UHV power transmission system construction have been made [35], the grid connection is still a big problem. The root cause of this problem is lack of motivation for the grid to integrate wind power. Therefore, RPS policy that force the grid to integrate mandatory proportion of wind power is necessary. The amendment of Renewable Energy Law requires grid companies to enhance the grid's capability to absorb the full amount of renewable power produced. More detailed provisions about RPS are expected in 2011 [48].

6.4. Coordination between central and local government

Coordination between central and local government is very crucial for the healthy development of wind power. For onshore wind power, previous regulation authorized Provincial Development and Reform Commission to approve the projects smaller than 50 MW,

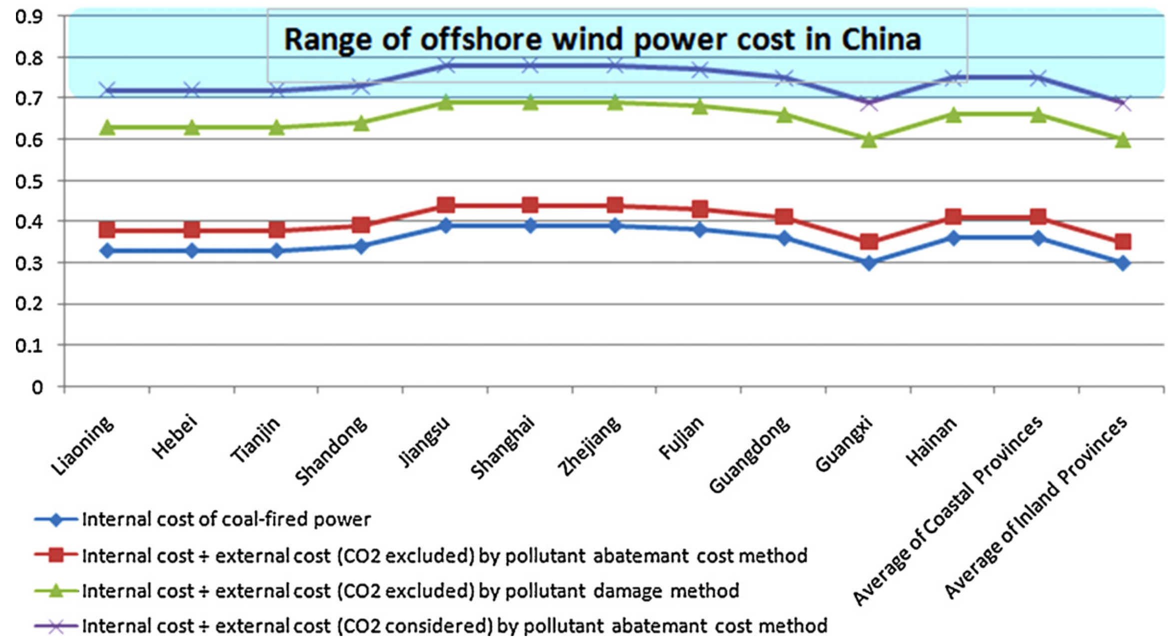

Fig. 8. Cost comparison between coal-fired power from different perspectives and offshore wind power in China's coastal provinces.

and this resulted in large amount of 49.5 MW wind farms, because local government is very active to approve wind power projects to increase the local tax revenue. It is not easy to say this kind of authorization mechanism is good or not, however, benchmark for offshore wind power should not be 50 MW, the same as onshore. That is because larger scale of offshore wind farm is more economical. Hence, coordination mechanism between central and local governments on approving the project should be improved.

Coordination for VAT tax raising is also needed. As mentioned in Section 4, change in VAT has made local government hardly get tax income during the first 7 years (even 13 years sometimes) of wind farms [50]. Therefore, it severely influenced the passion of local government to develop wind farms. Since local government can still enjoy levying taxes from manufacturing industry, this change of VAT happened to encourage local manufacturers to enlarge production capacity, or force local wind farms to purchase wind turbine produced by local manufacturers that results in overcapacity and local protectionism. This conflict should also be solved in the future, possibly by allowing local government to raise resource tax.

6.5. *Cost and economical analysis*

The cost of offshore power is the key factor that affects the scale of future offshore wind energy. Although offshore power is much more expensive than conventional coal-fired energy now, it also has two main competitive advantage. On the one hand, the price of coal keeps raising in recent years, and it is especially expensive in coastal provinces in China because they locate far away from the production area of coal. On the other hand, if external cost of coal is calculated, offshore power will be more competitive. The average external cost of pollutant (CO_2 excluded) emitted from coal-fired power plant in China is estimated at 0.05 RMB per kilowatt by pollution abatement cost method, and 0.30 RMB per kilowatt by pollution damage method. The cost will increase to 0.39 RMB if CO_2 is considered [51]. Fig. 7 compares these costs indicating that offshore wind power can be competitive if all the external cost of coal-fired power is internalized, especially in coastal provinces in China (we suppose the range of offshore wind power cost is from 0.7 RMB to 0.9 RMB) (see Fig. 8).

6.6. *Low bidding price in concession and SOE player*

In the first round of offshore wind power concession, successful bidders of four projects are all SOE players, which leads to discussion of efficiency of concession mechanism and SOEs' participation in wind power development.

Similar discussion occurred during the process of onshore wind power development. In 2003, concession mechanism – the "Tariff Reform Program" was announced for large wind power projects which were controlled by the central government through the NDRC. In this system, the NDRC announced investment plans and invited investors to submit tender offers – or rather bids – specifying the lowest price at which the investor was prepared to supply electricity to the grid. However, this bidding mechanism made SOEs get advantages. Wang [52] and Liu [53] both pointed out that SOEs were willing to offer very low price because they had relative softer budget constraints and motives than profits, such as local employment, production, tax revenue, and growth rates. Thus, several concession projects were severely delayed because of not covering their cost. Similar cases happened in concession in UK before as well [54,55]. Moreover, low price strategy of SOEs led investment from private and foreign sector stay out of the industry [56], as well as quality problems of turbine happen because of low cost pressure from SOE developers [57]. To discourage excessively low bids, the NDRC changed the successful bidder of concession from the lowest bid to the average bidding price in 2007, then, feed-in-tariff policy took the place of concession.

Therefore, we can conclude that concession is the process to find the true cost of power generation, and low bidding price in the early rounds of concession is reasonable. When the price is becoming stable, concession will be replaced because of efficiency. We can expect China government better utilize concession mechanism to spur offshore wind power development, and create a free-competitive market for wind power manufacturing.

6.7. *International support*

International support has greatly improved onshore wind energy development in China. Beside technology transfer mentioned previously, CDM plays an important role to make wind

power more economical. By the end of April 2009, the Chinese government approved 1766 CDM projects in total, and 337 of these were wind power projects. Further, approximately 95% of the wind power projects which do not belong to the wind power concession projects are CDM projects. The wind farm investors could get an economic incentive of approximately 0.1 RMB/kWh on average from CDM projects [58]. However, many wind power projects were rejected by CDM EB recently [59], and the situation for offshore wind power with CDM support is unclear.

Beside CDM, international cooperation projects focused on capacity building of China authorities when developing renewable energy is also very helpful. For example, Energy Research Institute, China Hydro Consultant Group and other decision supportive institutions in China has enjoyed methodologies and experience shared by National Renewable Energy Laboratory (NREL) under the framework of Sino-American Strategic Energy Cooperation for a long time. Also, Wind Energy Development (WED) Program initiated by Danish and Chinese government has improved the framework, plans and capacities on effective exploitation of wind energy from wind energy resources assessment, wind farm planning, grid Integration, to training and dissemination. Before successful conclusion of WED in 2010, Danish and Chinese government launched another collaborated program – Sino-Danish Renewable Energy Development (RED) Program to enhance national capacity to develop the renewable energy sector in China and Danish-Chinese institutional and business partnerships. Moreover, there also exist lots of international cooperation projects between universities and NGOs, which will definitely promote offshore wind power development.

7. Conclusion

Offshore wind energy is booming in China together with steady growth around the world. Unlike European countries which have almost already finished onshore wind development, and have to accelerate offshore wind development, there is still huge potential for China to develop onshore wind. Also, China has some unique advantages and challenges for offshore wind energy development. Therefore, more caution is needed when talking about offshore development in China.

Offshore wind is now at the initial stage. The coming years are playoffs for the China wind power development which is still far from the vision of significant supplement to energy mix. Such a market currently shows no commercial capacity. China needs to carefully formulate planning, summarize experience of demonstration projects, and see how the four pilot projects go before it makes any further decisions about further concession.

With the pace of offshore energy development, capacities of China's wind power industry have been greatly enhanced. Utilizing multiple mechanisms of technology transfer and development, Chinese manufacturers have preliminarily mastered offshore wind power technologies. To narrow the gap between the most advanced turbine, upgraded capacity of material processing is still needed. Moreover, China should pay more efforts in the size and quality of turbine, grid connection and RPS, coordination between central and local government, better mechanisms for concession and SOEs' participation, internalization of coal-fired power's external cost, and international cooperation.

Generally, the development of China offshore wind power will follow a more expedient mode, based on the onshore experiences, which will pave the way for the offshore market to rapidly unlock the massive offshore wind resources existing around the county.

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